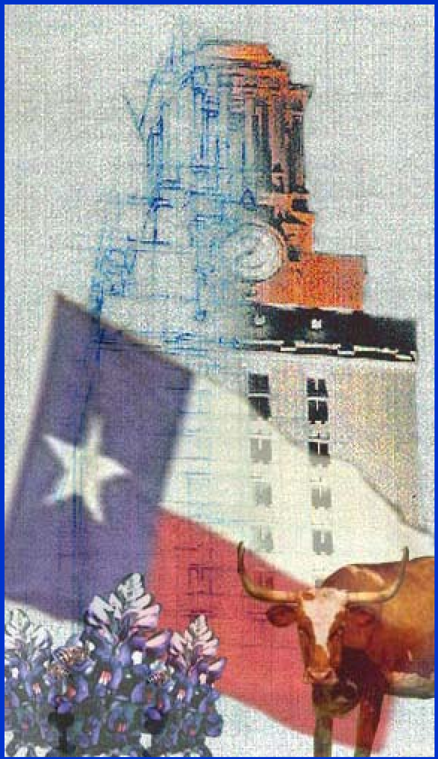
Ground Motion Prediction Equations and Seismic Hazard Assessment



Prof. Ellen M. Rathje, Ph.D., P.E.

Department of Civil, Architectural, and Environmental Engineering
University of Texas at Austin

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Seismic Design Framework

Source Characterization

Locations of sources (faults)

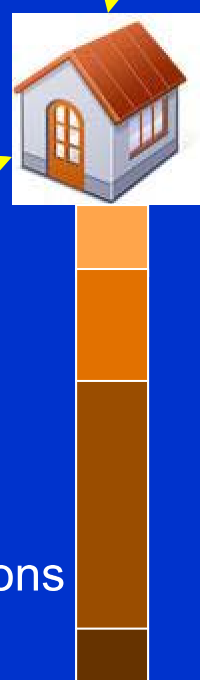
Magnitude (M_w)

Recurrence

Ground Motion Characterization

Closest distance fault to site (Rcl)

Local site conditions



R_{rup}

Soil conditions

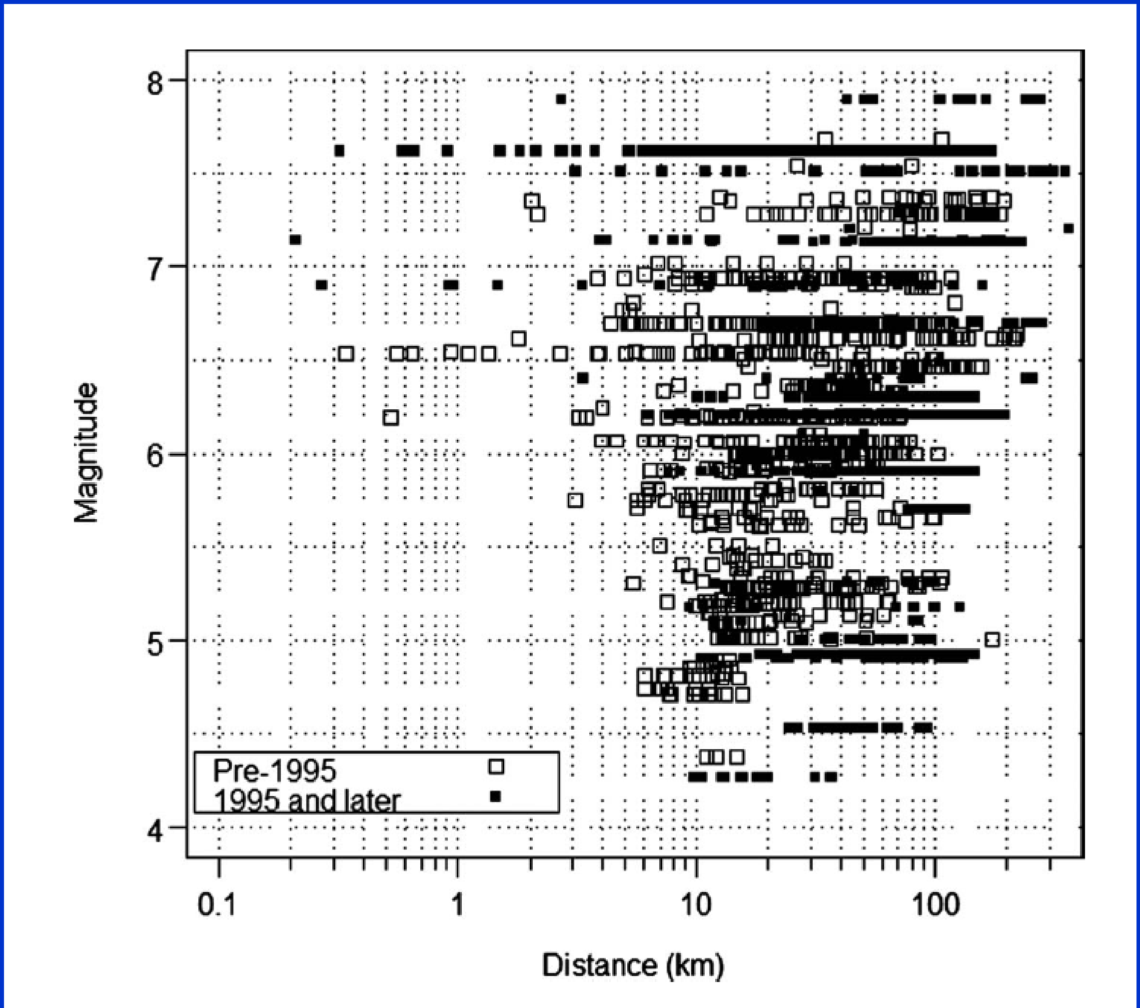
Topographic conditions

Ground motion = fxn (magnitude, distance, site conditions)

Predicting Ground Shaking

- Ground motion prediction equations (GMPE)
  - Statistical models to predict ground shaking
  - Developed for different tectonic regions (shallow crustal regions, subduction zones, intra-plate)
- Next Generation Attenuation (NGA) Project
  - GMPEs for shallow crustal earthquakes (appropriate for Haiti, based on available data)
  - Based on a consistently processed dataset of recordings
  - Five models generated by 5 separate teams

NGA Database



- 3551 recordings
- 173 earthquakes
- M_w = 4.2 - 7.9

Recordings available at http://peer.berkeley.edu/nga

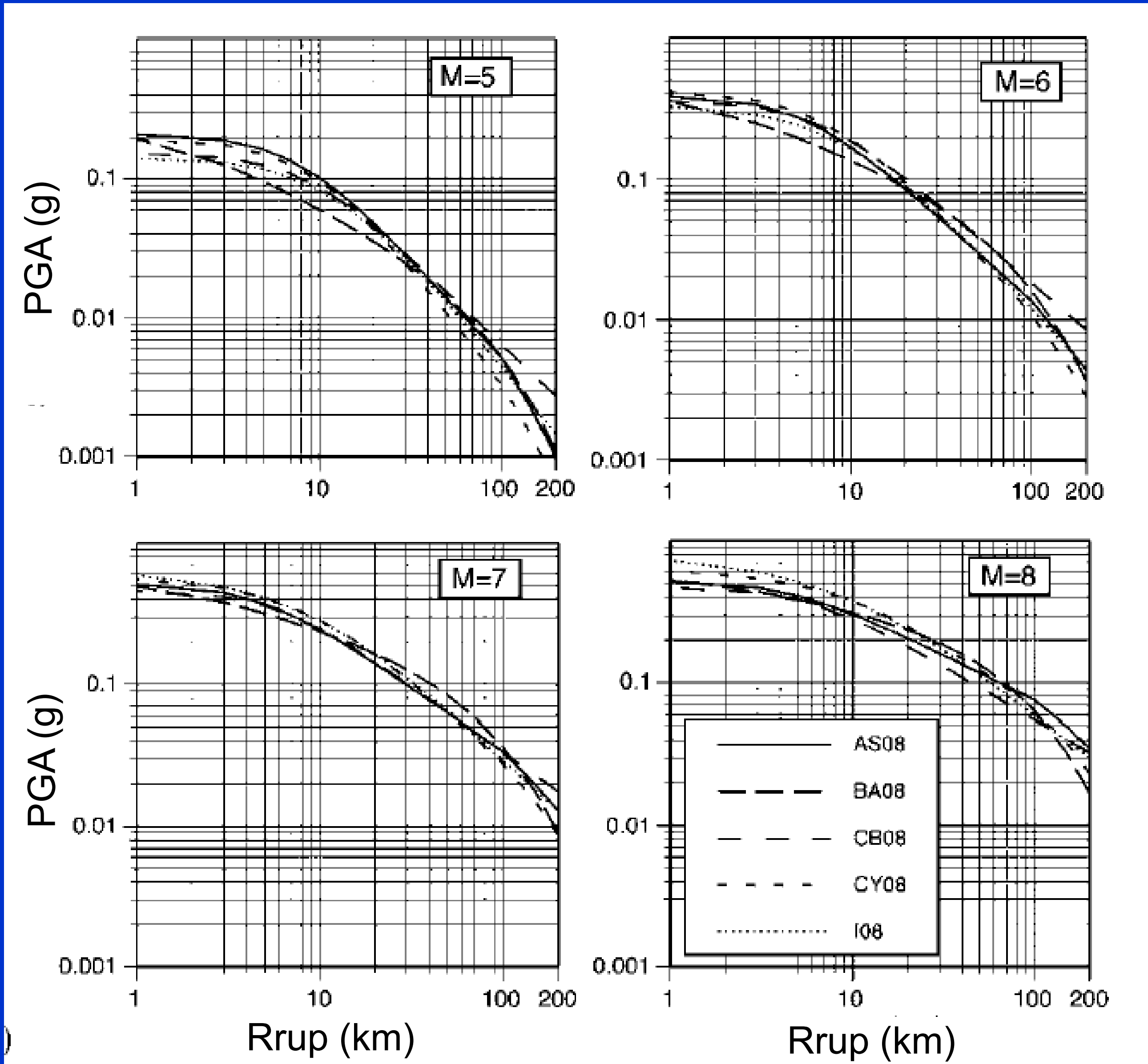
NGA Models

$\ln(Y) = f_{source}(M, \text{mechanism}) + f_{distance}(M, R_{rup})$
$+ f_{site}(V_s, \text{others})$

where Y = spectral acceleration at period, T

- Key Parameters
  - M: moment magnitude
  - Style of faulting (mechanism): reverse, strike-slip, normal
  - R_{rup}: distance to fault rupture plane
  - Vs30: average shear wave velocity in top 30 m
  - Z1.0: depth to Vs = 1.0 km/s

PGA Predictions



Motions attenuate with distance

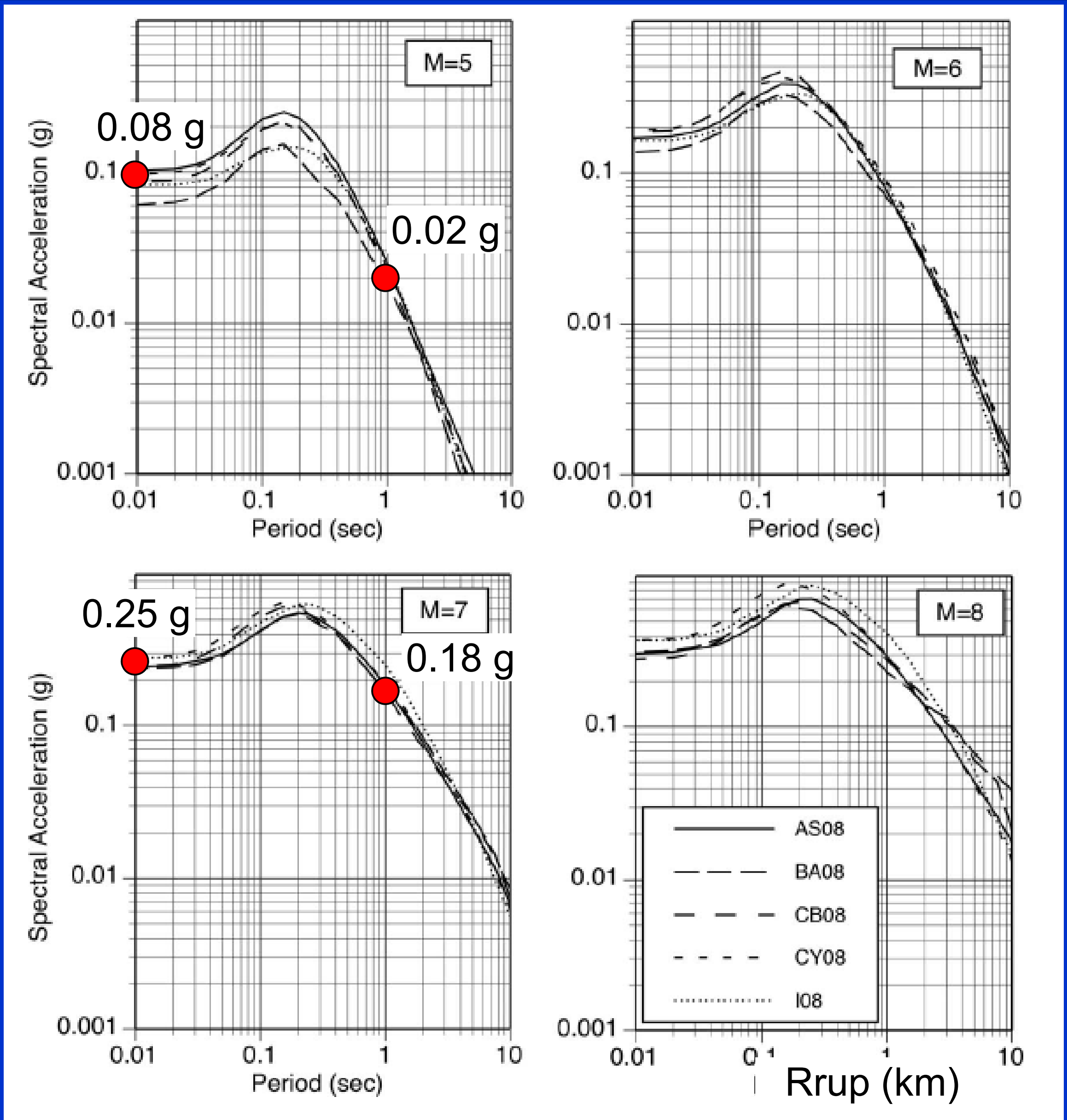
Larger M events attenuate more slowly

Response Spectra Predictions

R_{rup} = 10 km
Vs30 = 760 m/s
(Rock)

PGA:
M7 is 3x larger than M5

Sa at T = 1.0 s:
M7 is 9x larger than M5

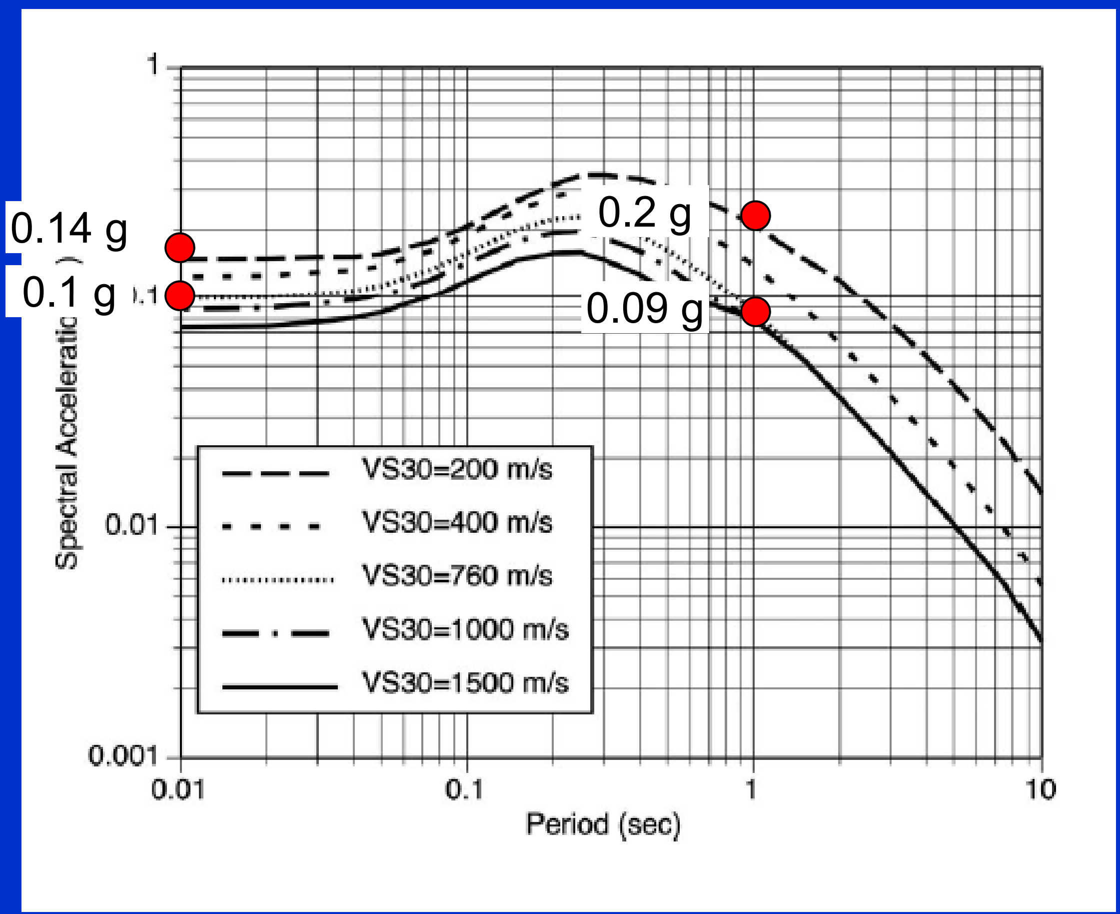


Influence of Vs30: Site Effects

M = 7, R_{rup} = 30 km
Vs30 = 760 m/s ("Rock")

PGA:
200 m/s is 1.4x larger than 760 m/s

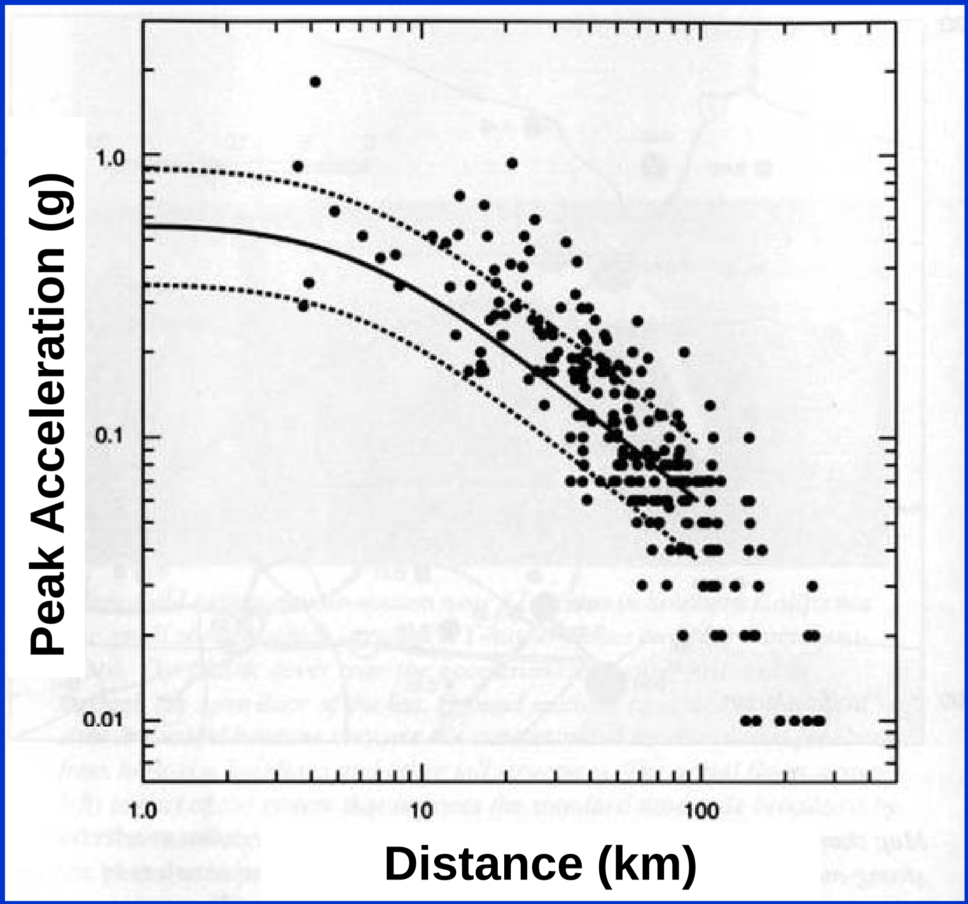
Sa at T = 1.0 s:
200 m/s is 2.2x larger than 760 m/s



Scatter in Ground Motions

- Given M, R_{rup} $\rightarrow$ large range of possible motions

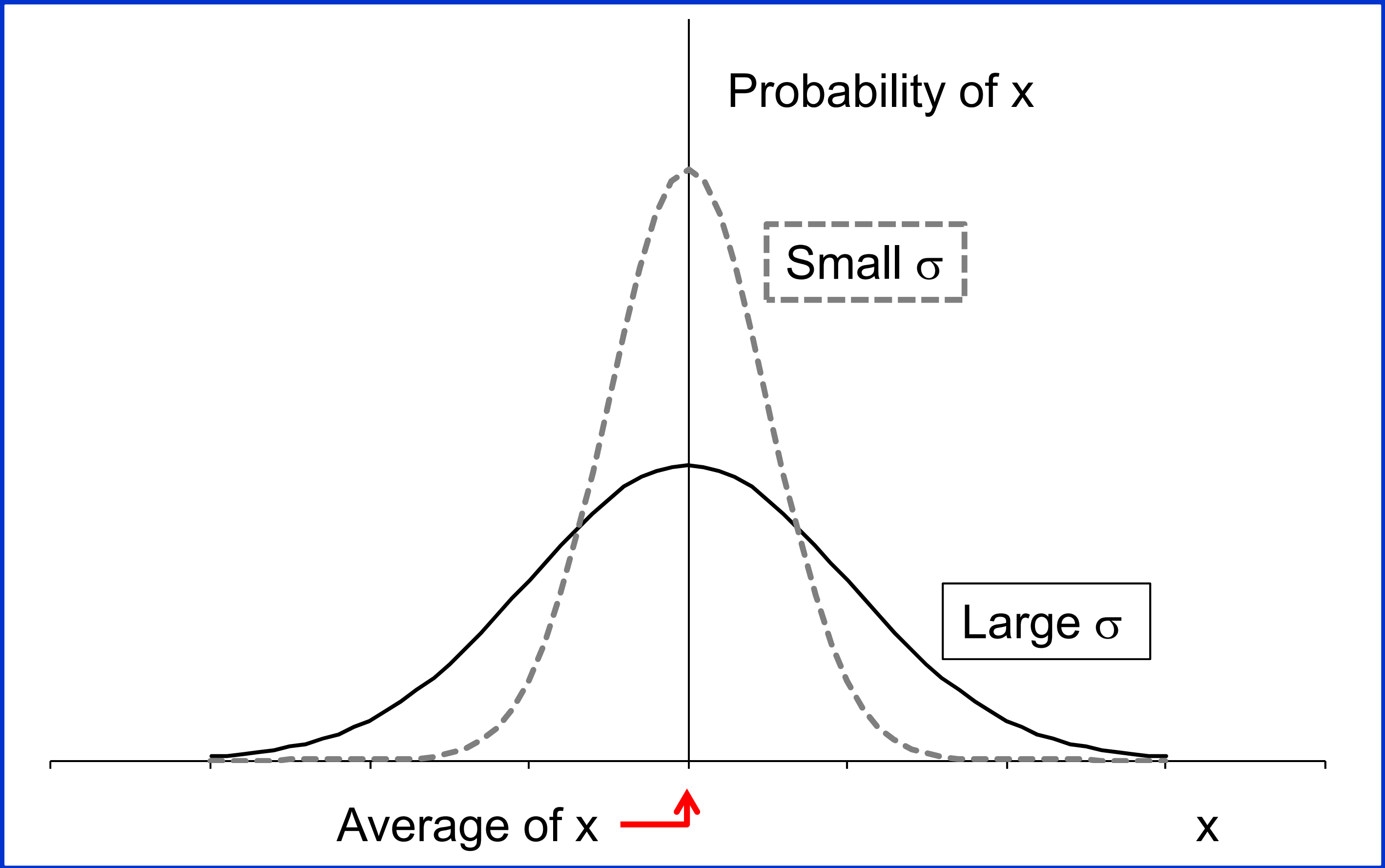
1994 Northridge (M_w = 6.7) Earthquake



From D. Boore

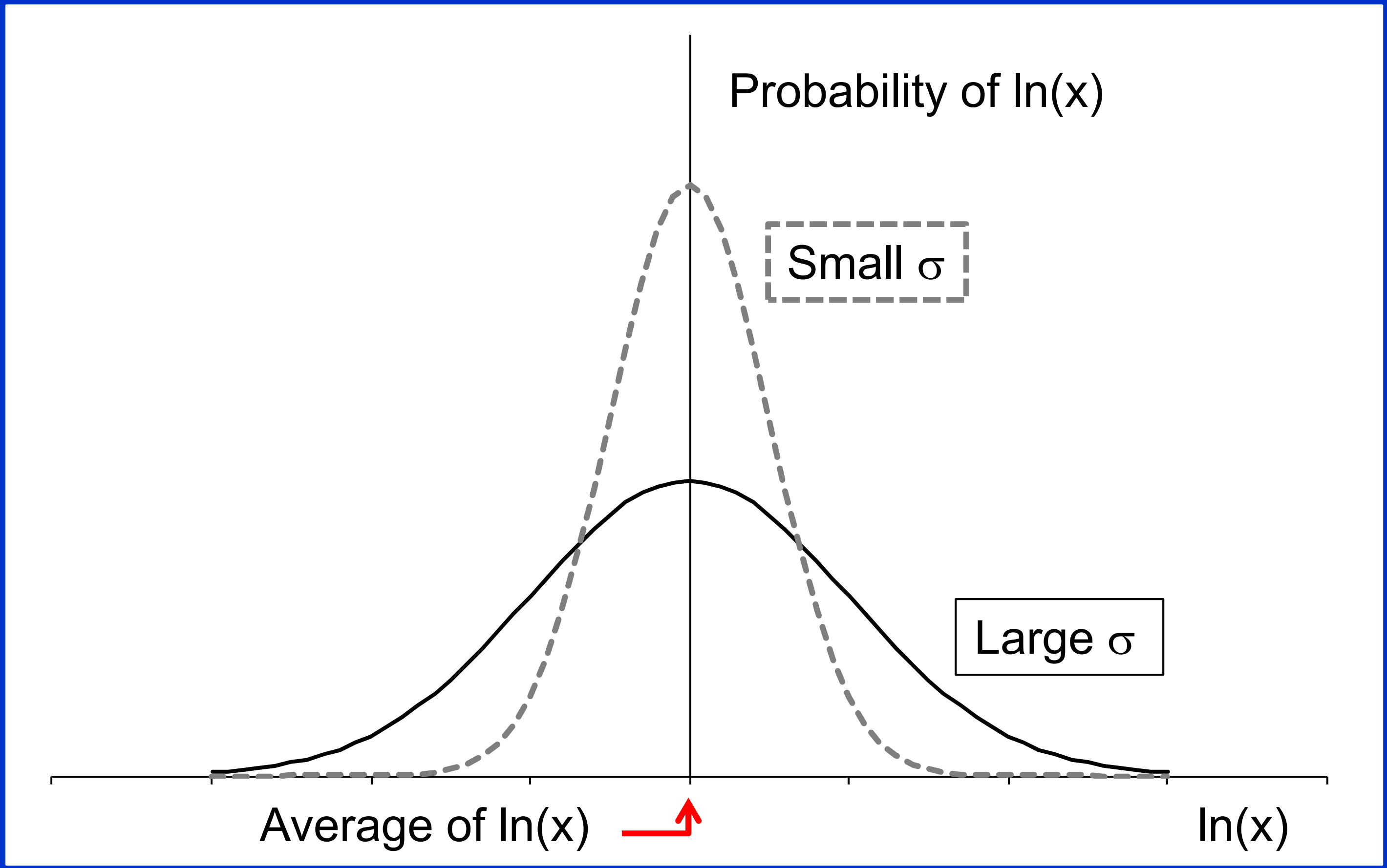
Standard Deviation

- Scatter measured by standard deviation, (sigma, σ), of **normal distribution**



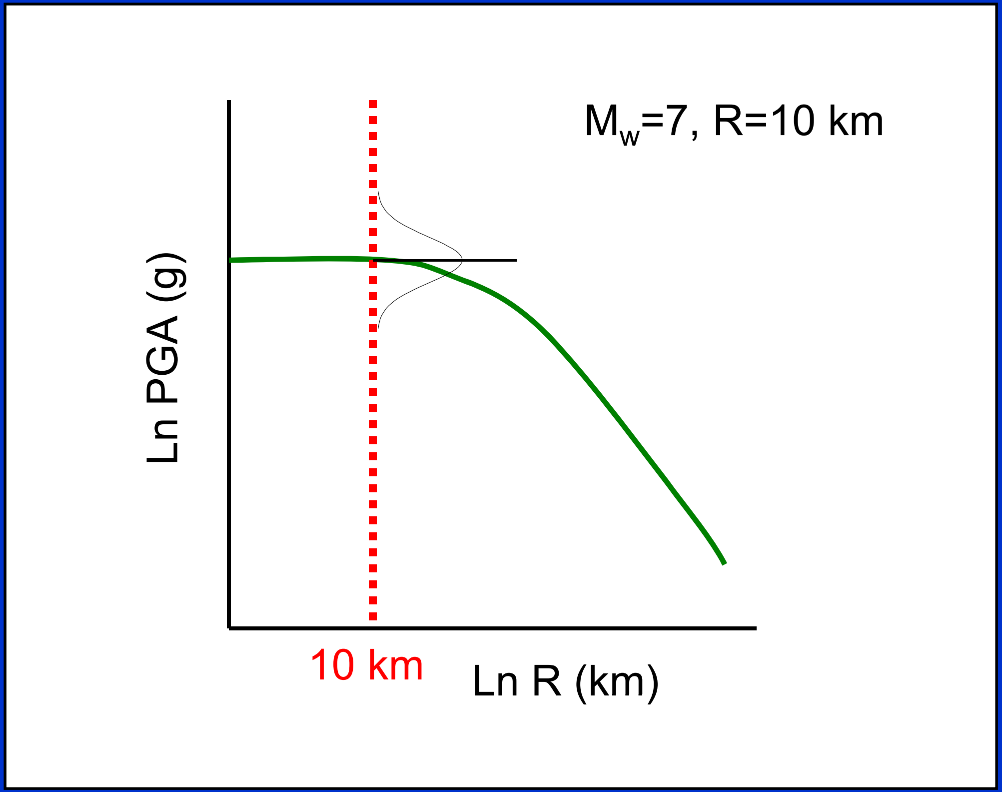
Sigma for GMPEs

- Ground motions are log-normally distributed (i.e., ln of x is normally distributed)



Sigma for GMPEs

- Given M, Rrup → GMPE provides average motion and its sigma (scatter)



σ ~ 0.55 to 0.70

For σ = 0.55, 90% chance value will fall within (1/3)·avg to 3·avg

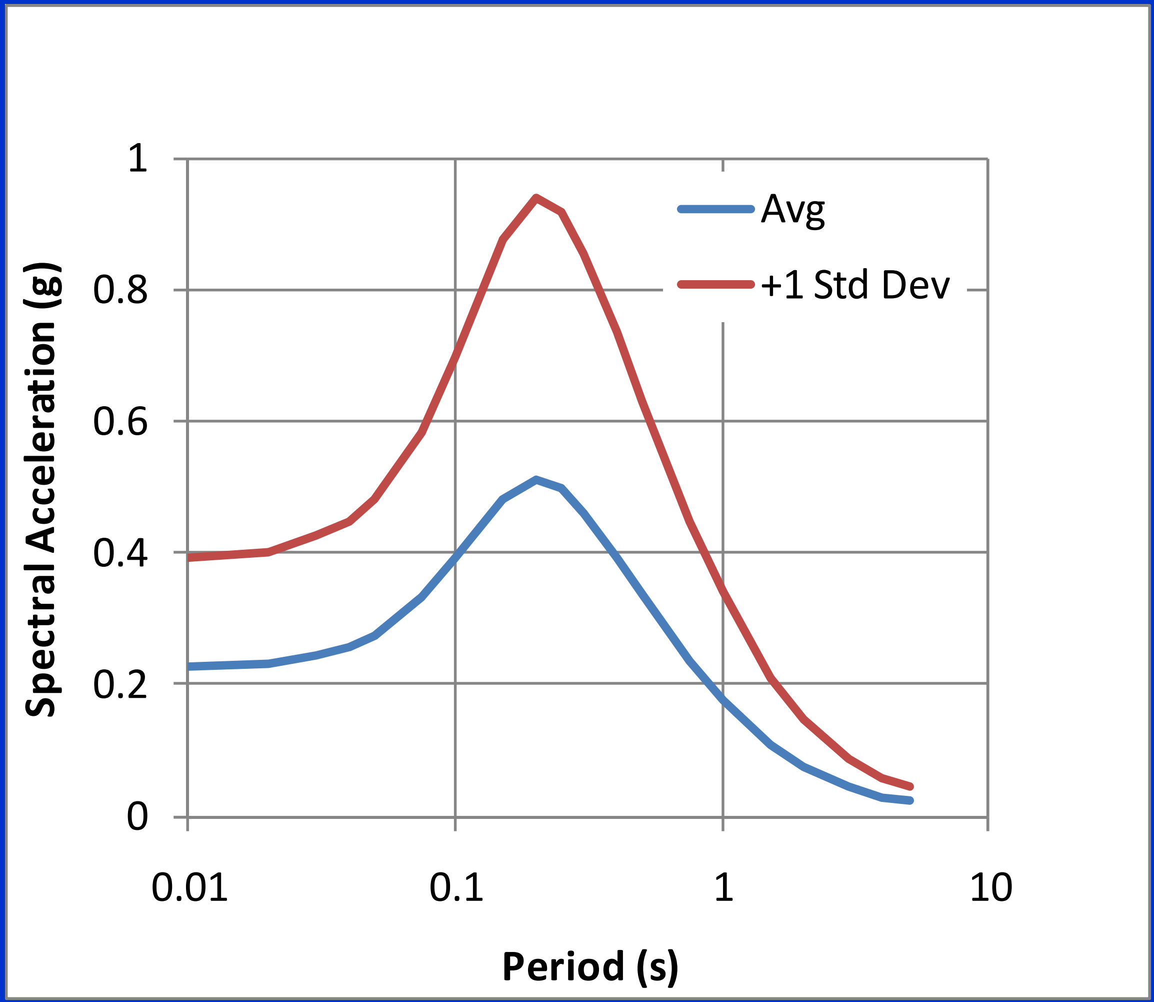
For example, if avg = 0.1 g, 90% chance value is between 0.03 and 0.3 g

Seismic Hazard Assessment

- Seismic hazard: expected ground motions
  - Deterministic and Probabilistic approaches
- Deterministic Seismic Hazard Assessment (DSHA)
  - Select <u>one</u> (or two) most likely M, R_{rup} scenarios
  - Predict ground shaking from GMPE (avg or $+1\sigma$)
- Probabilistic Seismic Hazard Assessment (PSHA)
  - Consider all M, R_{rup} scenarios, their expected ground motions, and how likely they are

DSHA

M = 7.0, R = 10 km → Response spectrum from GMPE

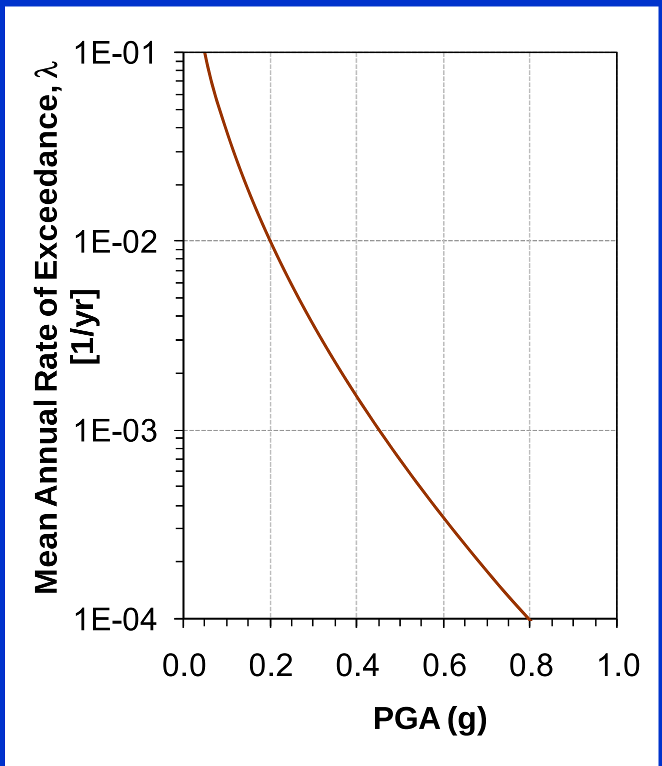


Seismic Hazard Assessment

- Probabilistic Seismic Hazard Assessment (PSHA)
  - Consider all M, R_{rup} scenarios
  - Consider all potential ground motion levels
  - Consider how likely each scenario and ground motion are to occur (i.e., probability)
  - Compute seismic hazard curve
- Building code design ground motions are derived from PSHA

PSHA

- Product: ground motion level and its annual rate of exceedance (λ = # times per year gm level exceeded)



Return period ~ (1 / λ)

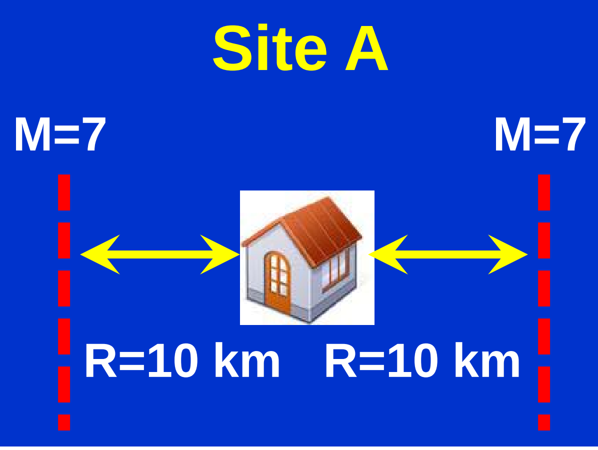
500 yr return period → λ ~ 0.002

2500 yr return period → λ ~ 0.0004

As λ ↓, ground motions ↑ because they are less likely

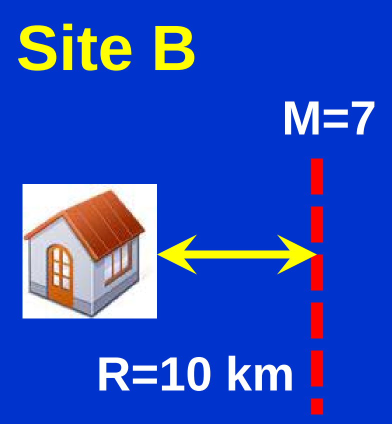
PSHA

- PSHA accounts for 4 things that DSHA does not
  - Large scatter (σ) in ground motion prediction
  - More small earthquakes than large
  - Activity rates (i.e., Number EQ/yr) vary from fault to fault
  - Increased hazard from multiple faults



DSHA:
Hazard A = Hazard B

PSHA:
Hazard A > Hazard B



Requirements for PSHA

- Rate of earthquakes and their distribution across magnitudes:
  - Magnitude recurrence
- GMPE to predict ground shaking levels and standard deviation given M, R_{rup}

Activity rate: No. of Eqs /yr

GMPE

$$\lambda_{GM}(z) = MRE_{GM}(z) = \lambda_o \cdot \int_m \int_r P\left[GM > z \middle| m, r\right] f_M(m)\, f_R(r) \cdot dmdr$$

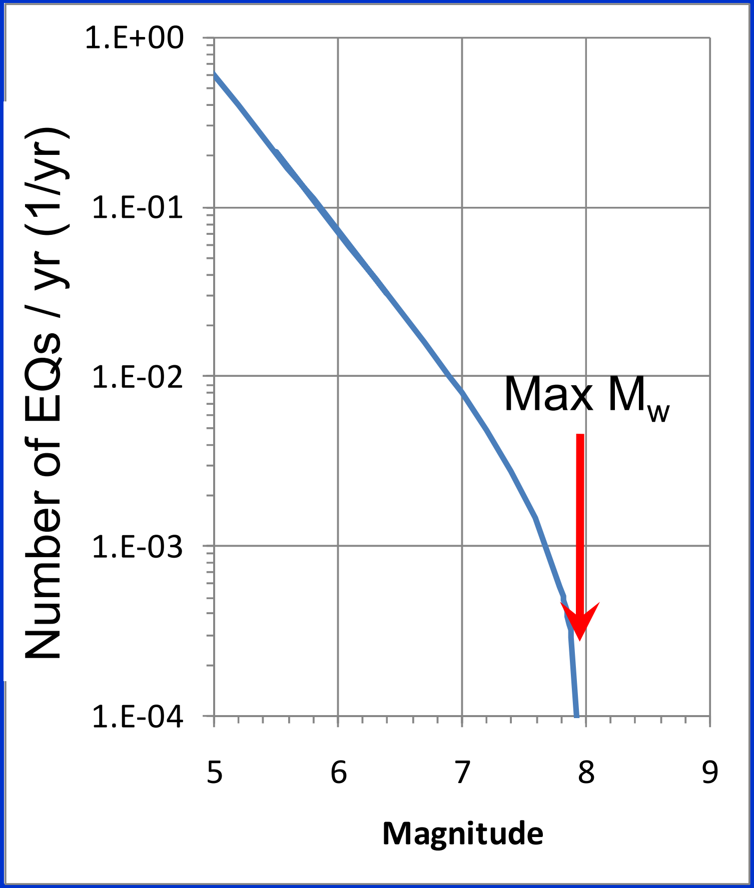
Annual rate of exceedance of gm level = “z”

P [M_i] P [R_j]

Mag Recurrence

PSHA

- Magnitude Recurrence
  - Number of small earthquakes vs. large



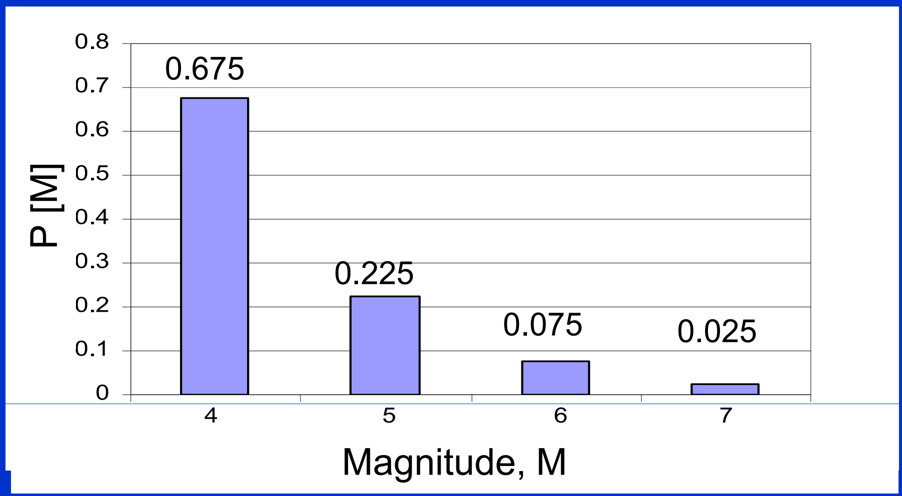
Defined using:

- ***Geodetic slip rates***
- ***Rates of small EQs***
- ***Fault length (M_{max})***

PSHA Calculation

Magnitude Distribution

Derived from magnitude recurrence

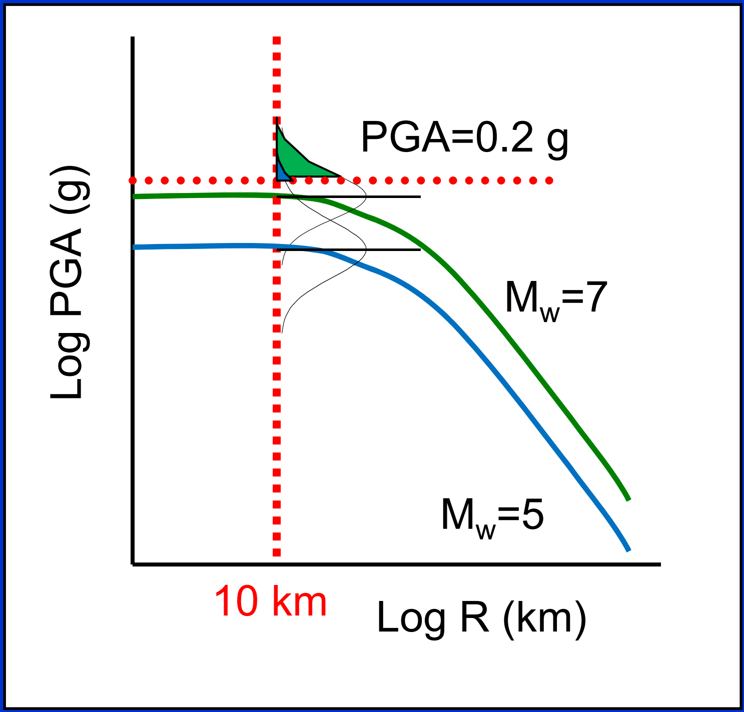


R_{rup} = 10 km for all earthquakes

Activity rate = 0.5 per yr

Ground Motion Prediction

How likely is PGA > 0.2 g for each M?



Probability [M=5] > Probability [M=7]

Prob [PGA > 0.2 g given M = 5] < Prob [PGA > 0.2 g given M = 7]

PSHA Calculation

$$\lambda_{PGA}(0.2g) = \lambda_o \cdot \sum_{m_i} \sum_{r_j} P\left[PGA > 0.2g \middle| m_i, r_j\right] \cdot P[m_i] \cdot P[r_j]$$

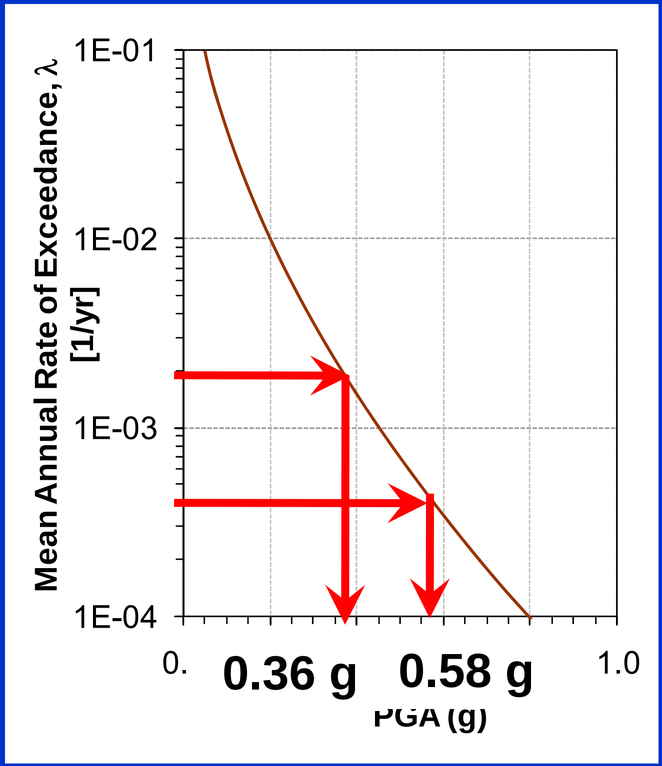
M	$P[m_i]$	P[r = 10 km]	P[PGA>0.2|m,r]	P[M] · P[PGA>0.2 g]
4	0.675	1.0	0.01	0.00675
5	0.225	1.0	0.05	0.02025
6	0.075	1.0	0.25	0.01875
7	0.025	1.0	0.58	0.01450

Sum = 0.06025
λ(0.2 g) = λ_o · 0.06025

λ (0.2 g) = 0.03012
Return Period ~ 33 yr

Hazard Curve

- Perform hazard calculation for multiple values of PGA to generate hazard curve



$\lambda \sim 0.002$ → 500 yr return period → 10% probability of exceedance in 50 yrs

$\lambda \sim 0.0004$ → 2500 yr return period → 2% probability of exceedance in 50 yrs

Disaggregation

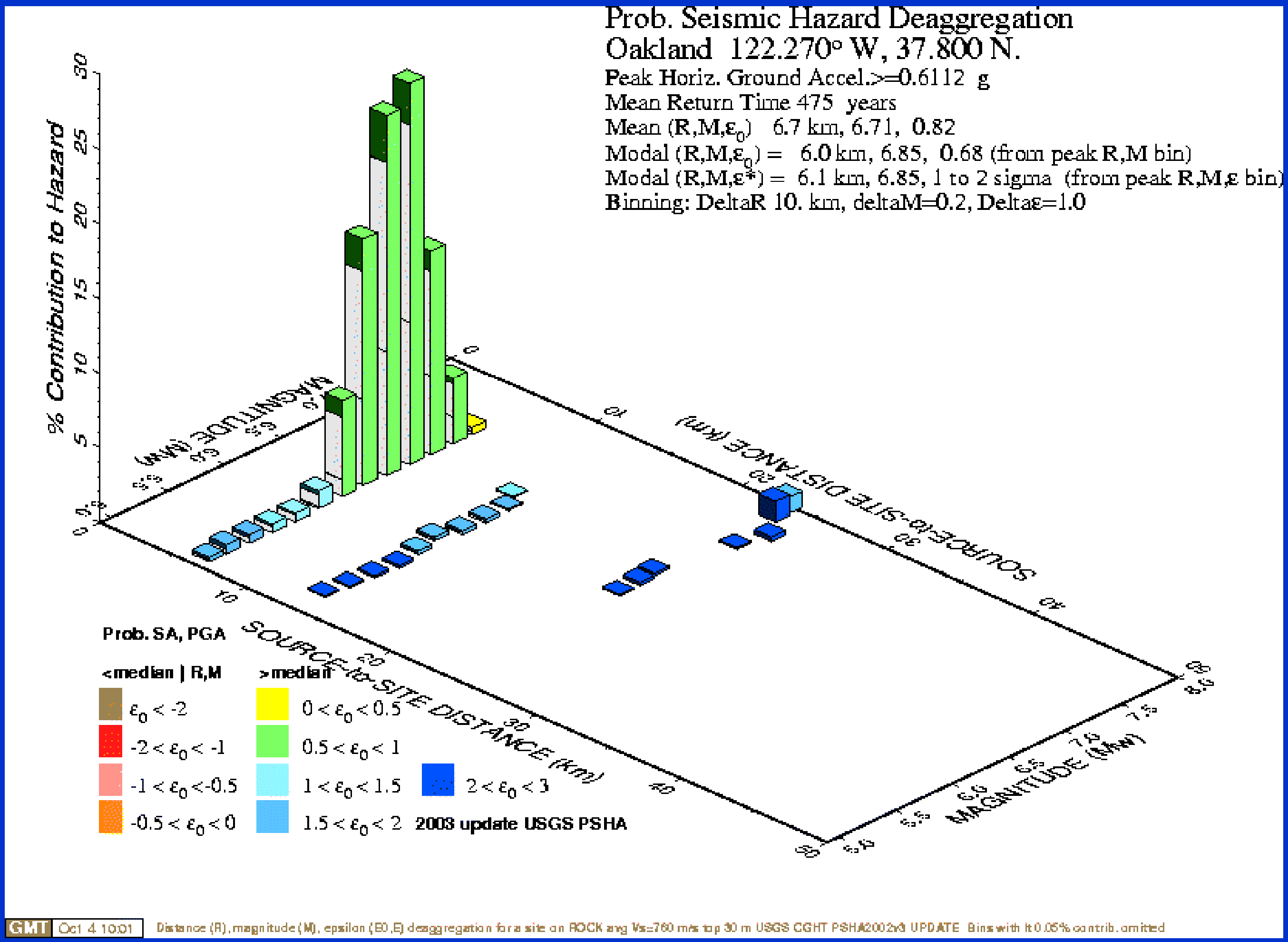
- What magnitudes and distances contribute most to ground motion hazard??

M	P[m_i]	P[r = 10 km]	P[M] · P[PGA>0.2 g]	% Contribution
4	0.675	1.0	0.00675	13%
5	0.225	1.0	0.02025	22%
6	0.075	1.0	0.01875	37%
7	0.025	1.0	0.01450	28%

M = 6 has the largest contribution and M = 4 smallest

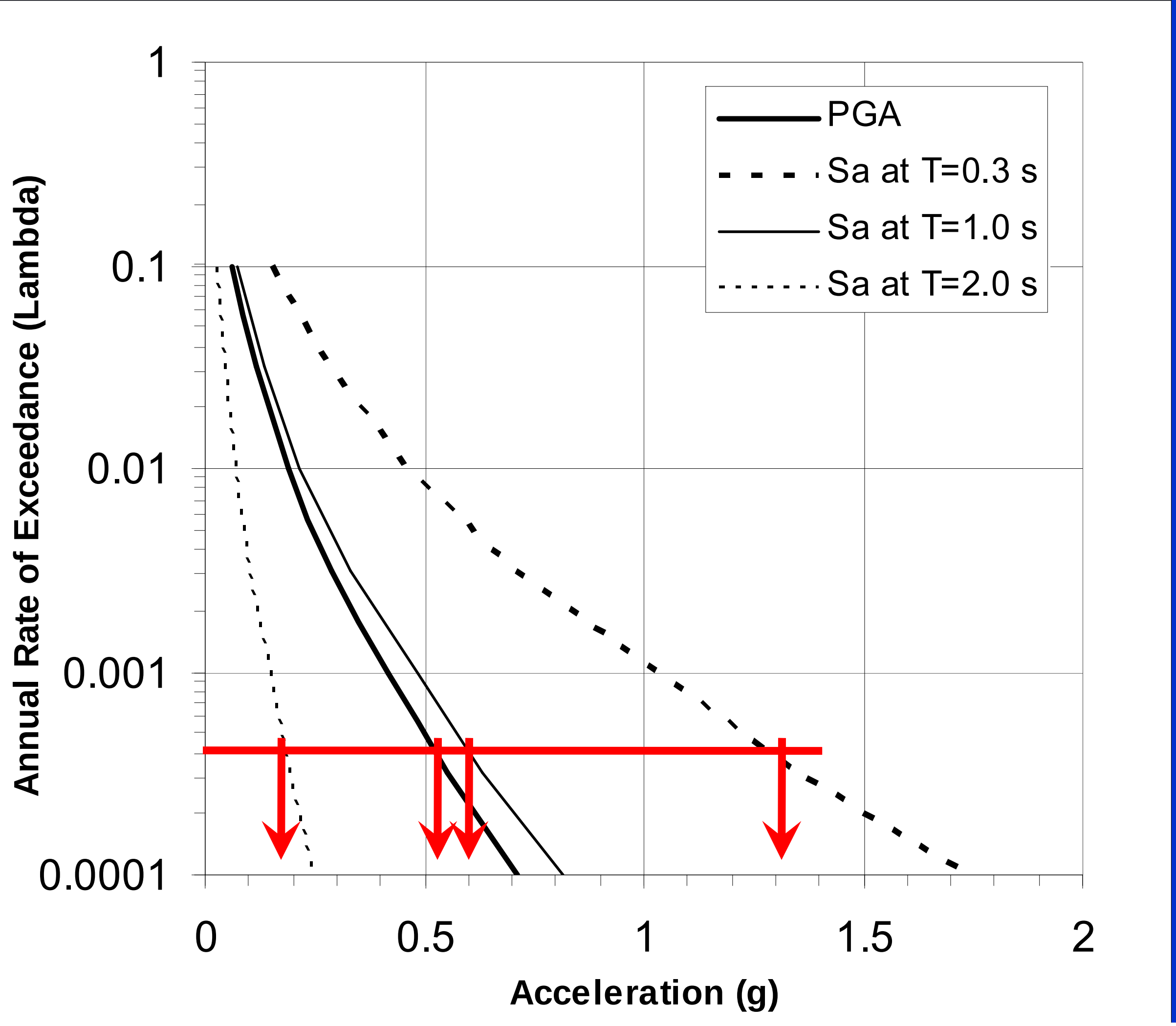
Disaggregation

Oakland, CA Disaggregation for 10% probability of exceedance in 50 yrs (500 yr return period)



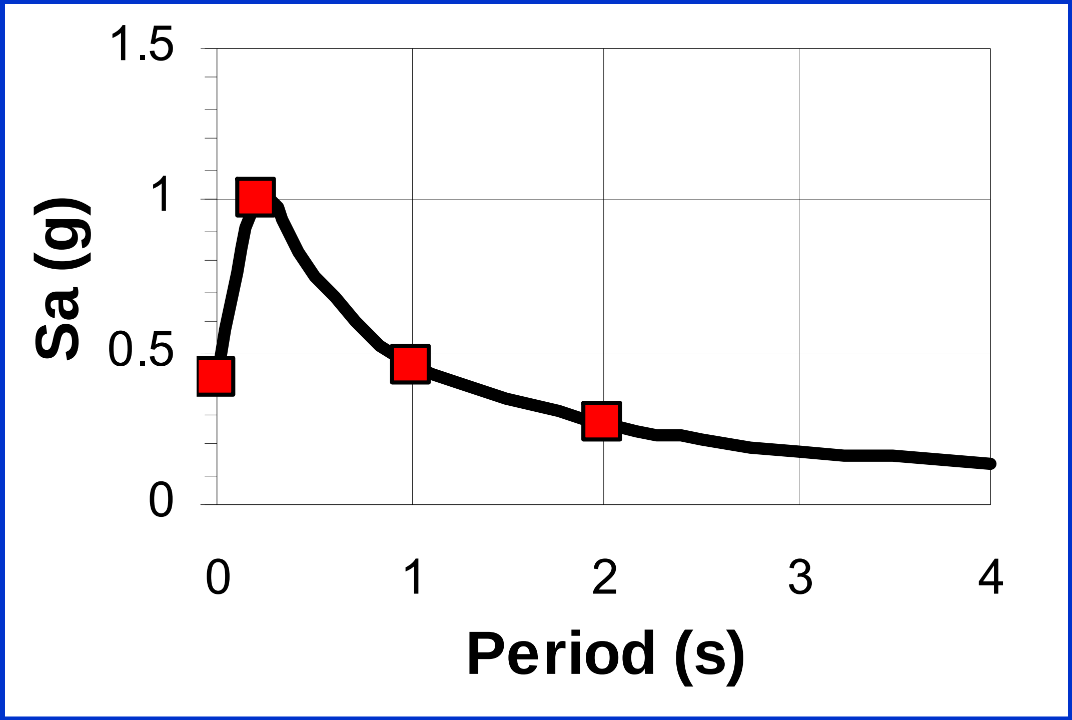
Uniform Hazard Spectrum

Develop hazard curves for multiple response spectrum periods



Uniform Hazard Spectrum

Plot Sa value from each hazard curve at its appropriate spectral period



Summary

- Ground motion prediction equations (GMPE)
  - Statistical models to predict ground shaking
  - Model the effects of M, R_{rup}, style of faulting, site conditions
  - NGA models represent the state-of-the-art in GMPEs for shallow crustal earthquakes
  - NGA models are currently believed to best represent ground shaking in Haiti (but recordings in Haiti will help confirm this!)

Summary

- Seismic Hazard Assessment
  - Deterministic seismic hazard analysis (DSHA) provides an "EQ scenario" of ground shaking
  - Probabilistic seismic hazard analysis (PSHA) considers all uncertainties (e.g., all potential earthquakes, rate of earthquakes, etc.)
  - PSHA has become the standard for defining ground motions used in design